REPORT

SUB-AUDIO MAGNETICS SURVEY
Rocklands and Lone Sub Block, Cloncurry, Qld
AUSTRALIA

POST-ACTIVITY REPORT

Gap Geophysics Australia Pty Limited

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Purpose of This Report

This report was commissioned for the purpose of a sub-surface geophysical investigation to map geological structure.

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Report prepared by: ________________

Lucas Heape
Project Manager

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SUB-AUDIO MAGNETICS SURVEYS
POST-OPERATIONS REPORT
Rocklands and Lone Sub Block, Cloncurry Queensland.

EXECUTIVE SUMMARY

Gap Geophysics Australia Pty Limited (GAP) was commissioned by CuDeco Limited to conduct a geophysical survey using GAP's proprietary Sub-Audio Magnetics (SAM) technique over four grids near Cloncurry, Queensland, Australia. The survey was carried out during the period 1st to 17th August 2009.

SCOPE AND OBJECTIVES OF THE SURVEY

The Statement of Work (SOW) specified that GAP was to use its Sub-Audio Magnetics technology to survey (in AGD 66/ UTM Zone 54 South coordinates) 4 grids totalling approximately 200 line km.

The deliverables for the project were as follows:

- A brief report on field activities, interpretation techniques and results.
- A digital copy of the Total Magnetic Intensity and Equivalent MMR data in Geosoft GDB and in ASCII XYZ (.XYZ) format.
- A digital copy of the Total Magnetic Intensity and Equivalent MMR data in Geosoft grid (.GRD) format.
- Colour images of the processed data as JPEG images.

PROJECT PERSONNEL

The Client representatives who arranged the survey was Peter Hutchison for CuDeco Limited. Lucas Heape led the project for GAP, with field operations carried out by Lucas Heape, Kelly Thomas and James Grindley.

SURVEY PROCEDURE AND INSTRUMENTATION

The Sub-Audio Magnetics survey procedures and instrumentation are described in detail in Appendix B. A summary of the instrumentation and data processing parameters applied to the surveys is shown in Table 1.

Roving Magnetometer Acquisition System	
Magnetometer	GAP TM-6 Magnetometer Controller - Synchronised with GPS 1PPS pulse
Sensor	Geometrics 822AS Cs Vapour
Sensor Elevation	~2.0 m
Sample Rate	1200 Hz
Sample Resolution	0.01nT
Base Station	
Magnetometer	Geometrics G856 Proton Precession
Sample Rate	0.1 Hz
Sample Resolution	0.1 nT
Excitation Source	
Transmitter	Zonge GGT-30 Geophysical Transmitter Transmitter Frequency 8 Hz, Current 10 Amps
Controller	GAP SAM-2 Controller - Synchronised with GPS 1PPS pulse
Duty Cycle	50%
Excitation Method	Galvanic – Grounded Dipole
Navigation & Positioning	
GPS	Trimble GPS Ag-114
Differential Corrections	Fugro OmniStar Real-time
Software	SAMUi – Gap Geophysics Pty Limited
Datum	AGD 66 - AMG Zone 54 S
Sample Rate	1 Hz
Nominal Survey line Direction	213Deg Rocklands, 90Deg Lone Block
Nominal Line Spacing	50 m
Data Processing Parameters	
TMI Sample Interval	~ 0.25 m
TFMMR Sample Interval	~ 1m
Gridding	Minimum Curvature
Cell Size	5m
TMI Filtering	None unless specified.
Images Produced	TMI_RTP, EQMMR, EQMMR_1VD,

Table 1 Instrumentation and data processing parameters used for the survey.

SURVEY RESULTS

The data were processed as described in Appendix B. Colour images of the data were produced and are provided on the accompanying CD as JPEG images.

Images were produced of the following:

- Survey Layout Map - This map also shows the current wire path and the electrode locations. The actual survey line paths and numbers are shown in black.
- Colour Image of Total Magnetic Intensity Reduced to Magnetic Pole (TMI_RTP)
- Colour Image of Equivalent MMR (EQMMR).
- Colour Image of Equivalent MMR – First Vertical Derivative (EQMMR 1VD).
- Colour Image of Equivalent MMR with contours of TMIRTP overlain.

Reduced scale copies of the images have been included in Appendix A for reference.

DIGITAL DATA PRODUCTS

The following files are supplied on the accompanying CD for each of the survey grids:

Files	Description
Grid Name.xyz	TMI and EQMMR in Geosoft XYZ Format
Grid Name.gdb	TMI and EQMMR in Geosoft Database Format
Grid Name TMI.grd	TMI grid file in Geosoft Format
Grid Name TMI_RTP.grd	TMI grid file in Geosoft Format
Grid Name EQMMR.grd	EQMMR grid file in Geosoft Format
Grid Name EQMMR 1VD.grd	EQMMR First Vertical Derivative grid file in Geosoft Format (upward continued 5m prior to taking 1VD)
Grid Name TMI_RTP .jpg	Colour Image of TMI in JPEG Format (upward continued 5m prior to processing RTP)
Grid Name EQMMR 1VD.jpg	Colour Image of EQMMR First Vertical Derivative in JPEG Format (upward continued 5m prior to taking 1VD)
Grid Name EQMMR.jpg	Colour Image of EQMMR in JPEG Format
Grid Name EQMMR TMI.jpg	Colour Image of EQMMR with Contours of TMI RTP in JPEG Format

Key:

- TMI – Total Magnetic Intensity
- RTP – Reduced To Magnetic Pole
- EQMMR – Equivalent Magnetometric Resistivity
- 1VD – First Vertical Derivative

FINAL REMARKS

- The terrain was mostly flat and open with an occasional steep rocky hill. The area was variably covered in scrub and Spinifex that made data acquisition and grid setup challenging in some parts.
- The thick scrub and steep slopes made some of the line paths torturous though elsewhere the lines were relatively straight.
- The south western corner of the Rocklands area contained some intensely magnetic geology.

Detailed interpretation of the data should be attempted by someone familiar with the geology in the area. The following points may help with the interpretation.

It should be noted that the earth's response to current channelling techniques such as SAM will, to some extent, be determined by the location of the current electrodes relative to the location of sub-surface conductors. For this reason, the amplitudes of anomalies from adjacent grids may not match perfectly. If conductive structures are continuous across survey boundaries they will generally be mapped in both grids although the amplitudes may differ slightly.

The colour scheme used for the EQMMR images and grids produced show areas of conductivity highs as red/pink and areas of conductivity lows as blue/white. This effectively means highs are relatively conductive regions and lows are resistive regions.

APPENDIX A – IMAGES

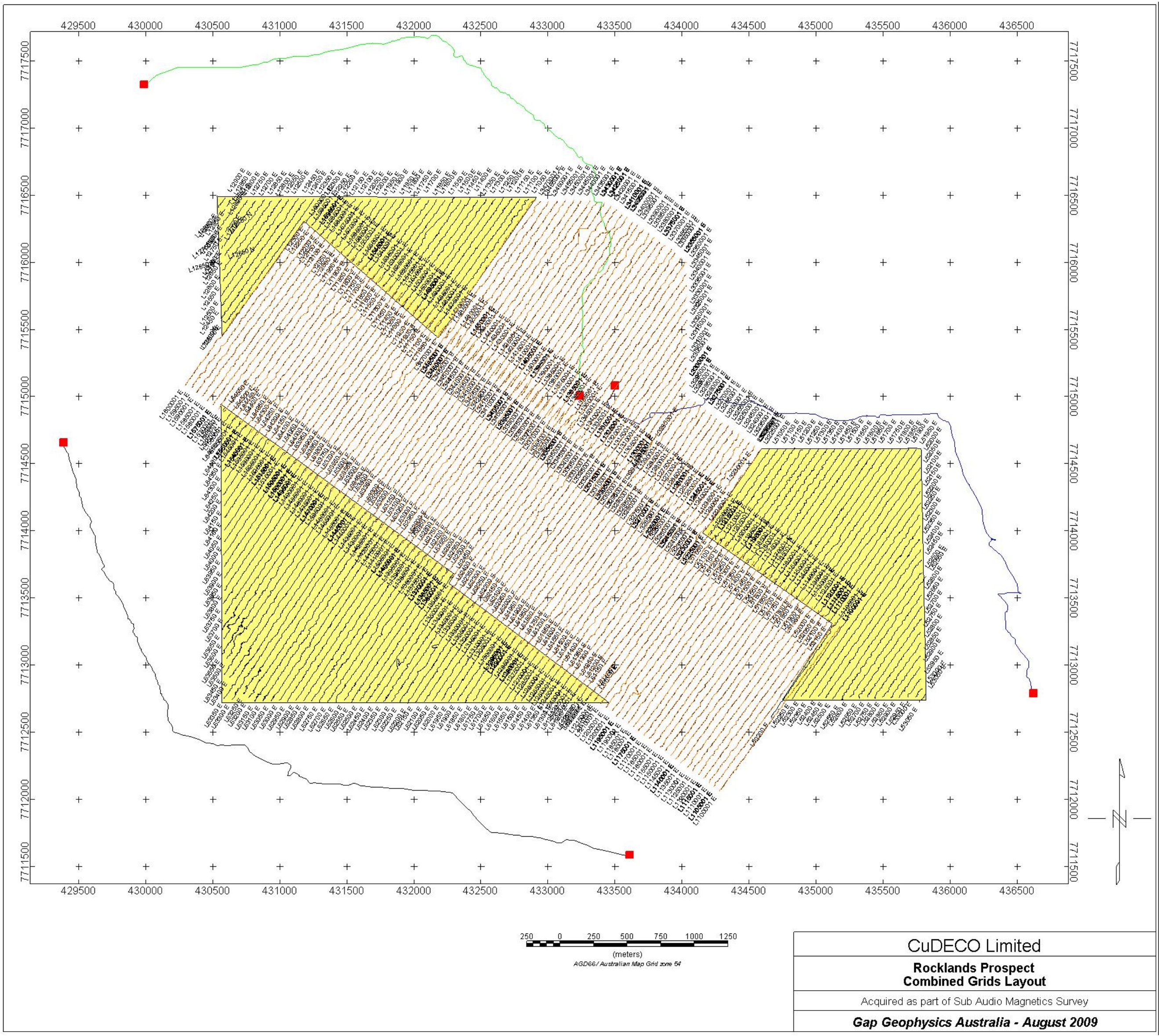

Figure 1 Rocklands – Layout, showing the current wire path, survey lines and line numbers

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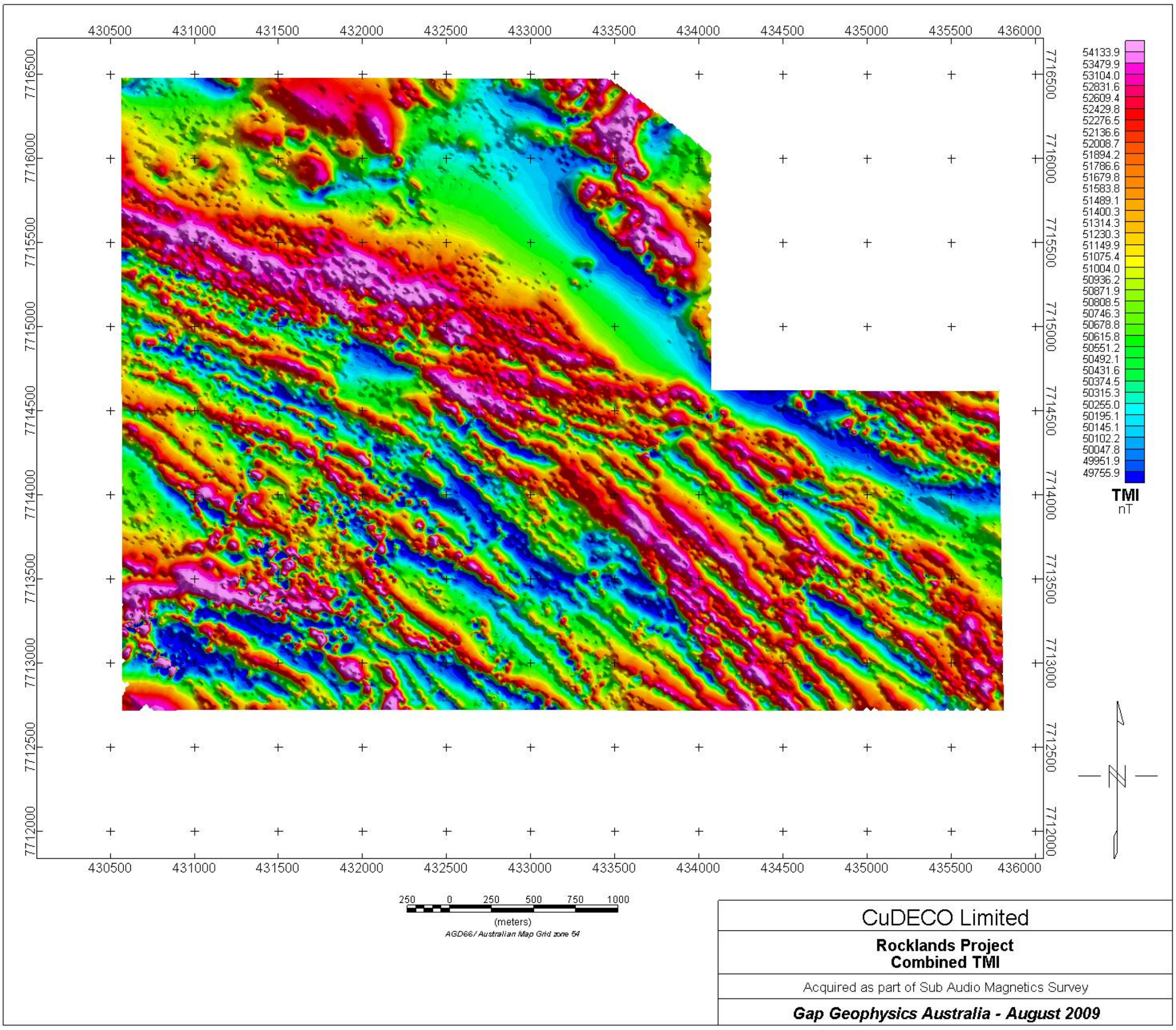

Figure 2 Rocklands Combined Grids - colour image of Total Magnetic Intensity.

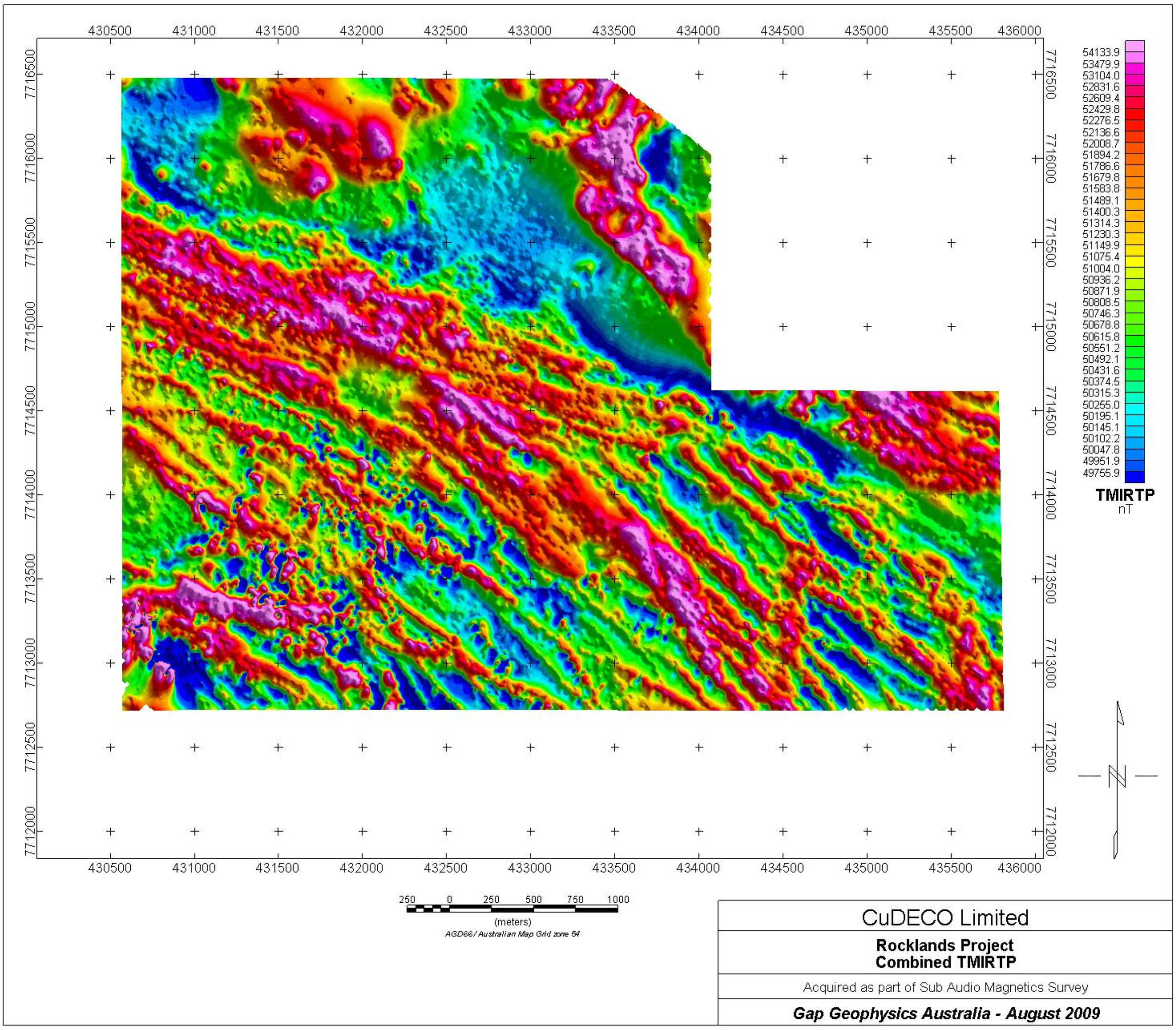

Figure 3 Rocklands Combined Grids – colour image of Total Magnetic Intensity Reduced to Magnetic Pole.

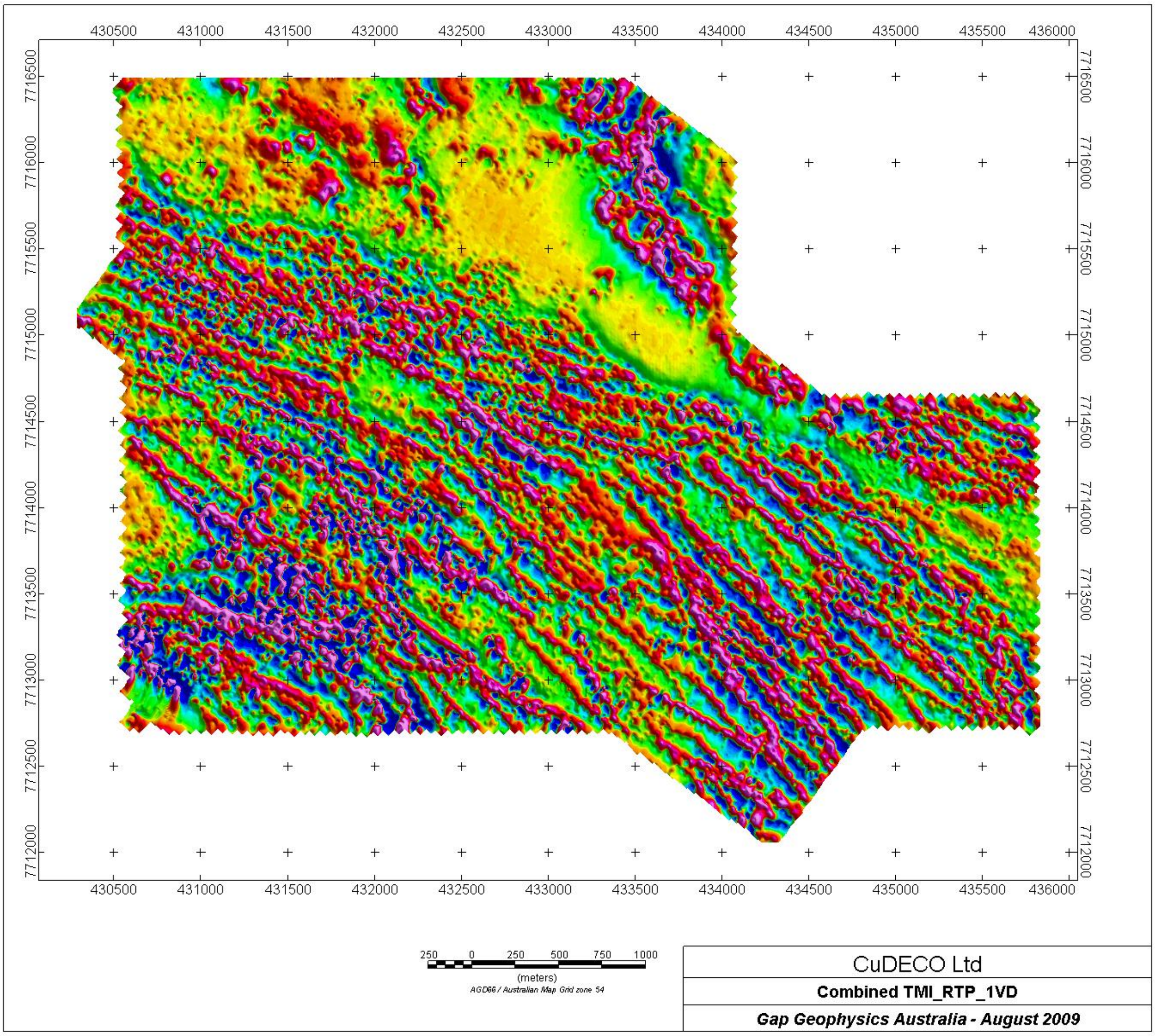

Figure 4 Rocklands Combined Grids – Colour image of TMI_RTP first vertical derivative. TMIRTP has been upward continued 10m prior to taking 1VD.

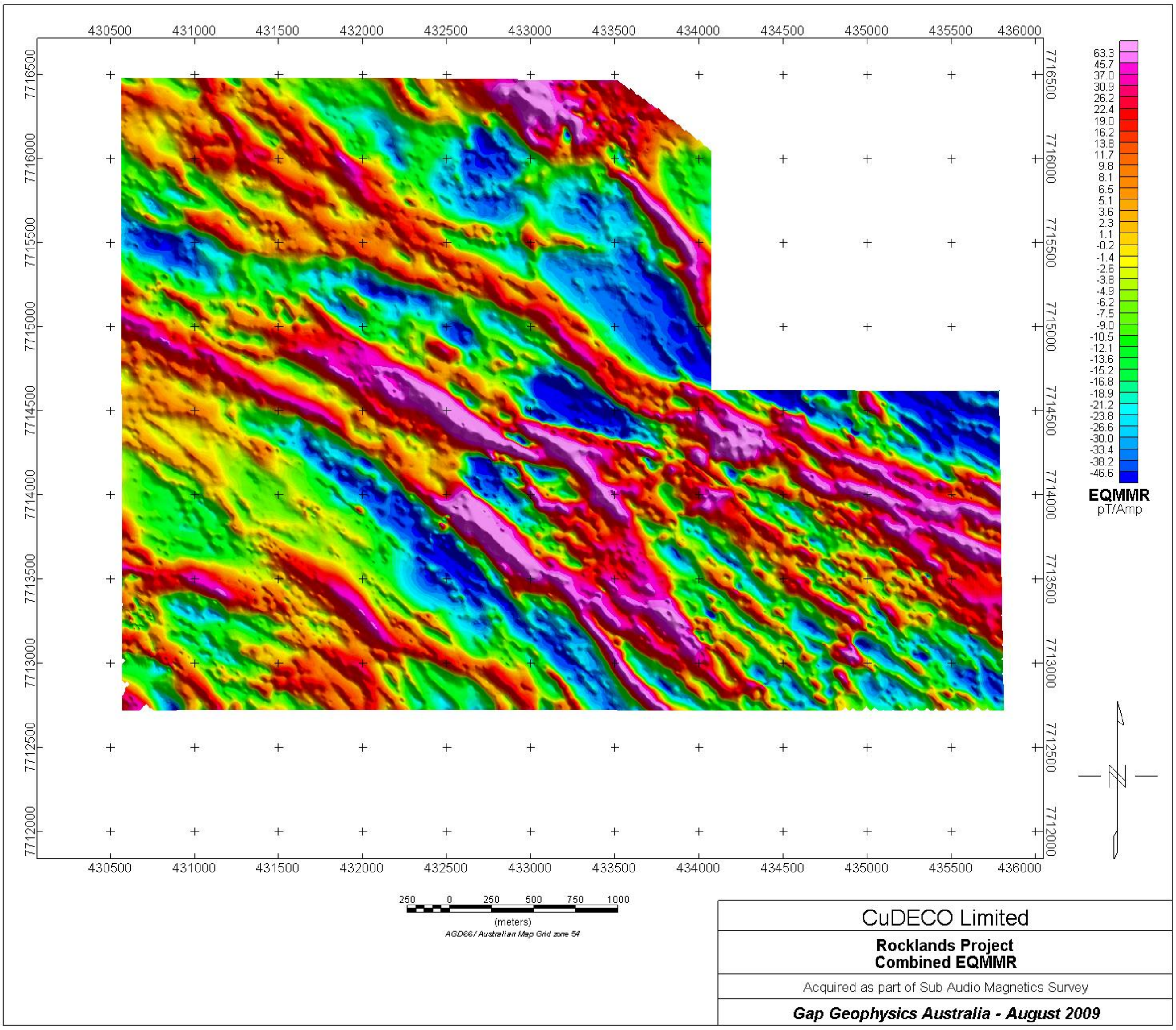

Figure 5 Rocklands Combined Grids – colour image of EQMMR.

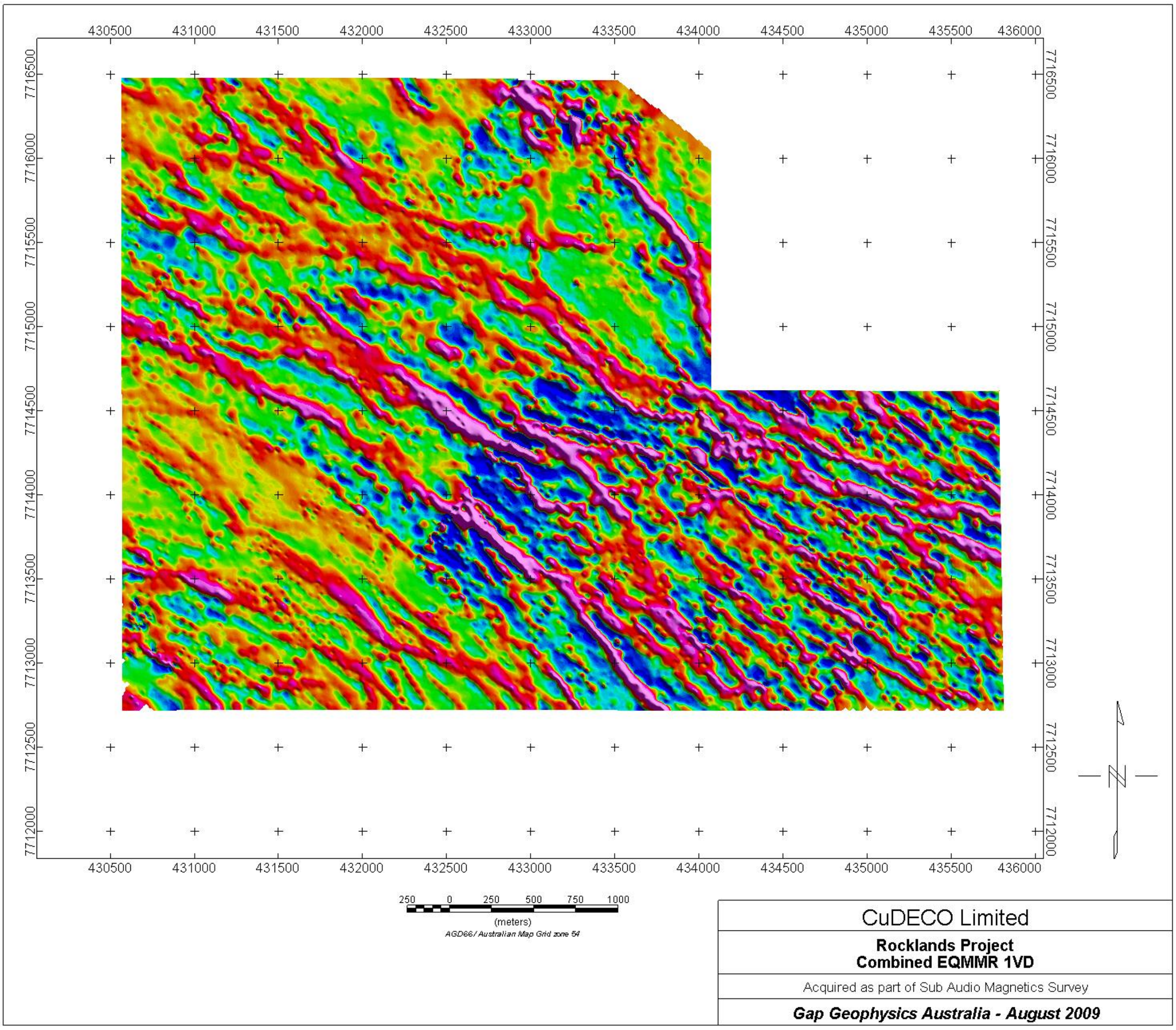

Figure 6 Rocklands Combined Grids - Colour image of EQMMR first vertical derivative. EQMMR has been upward continued 5m prior to taking 1VD.

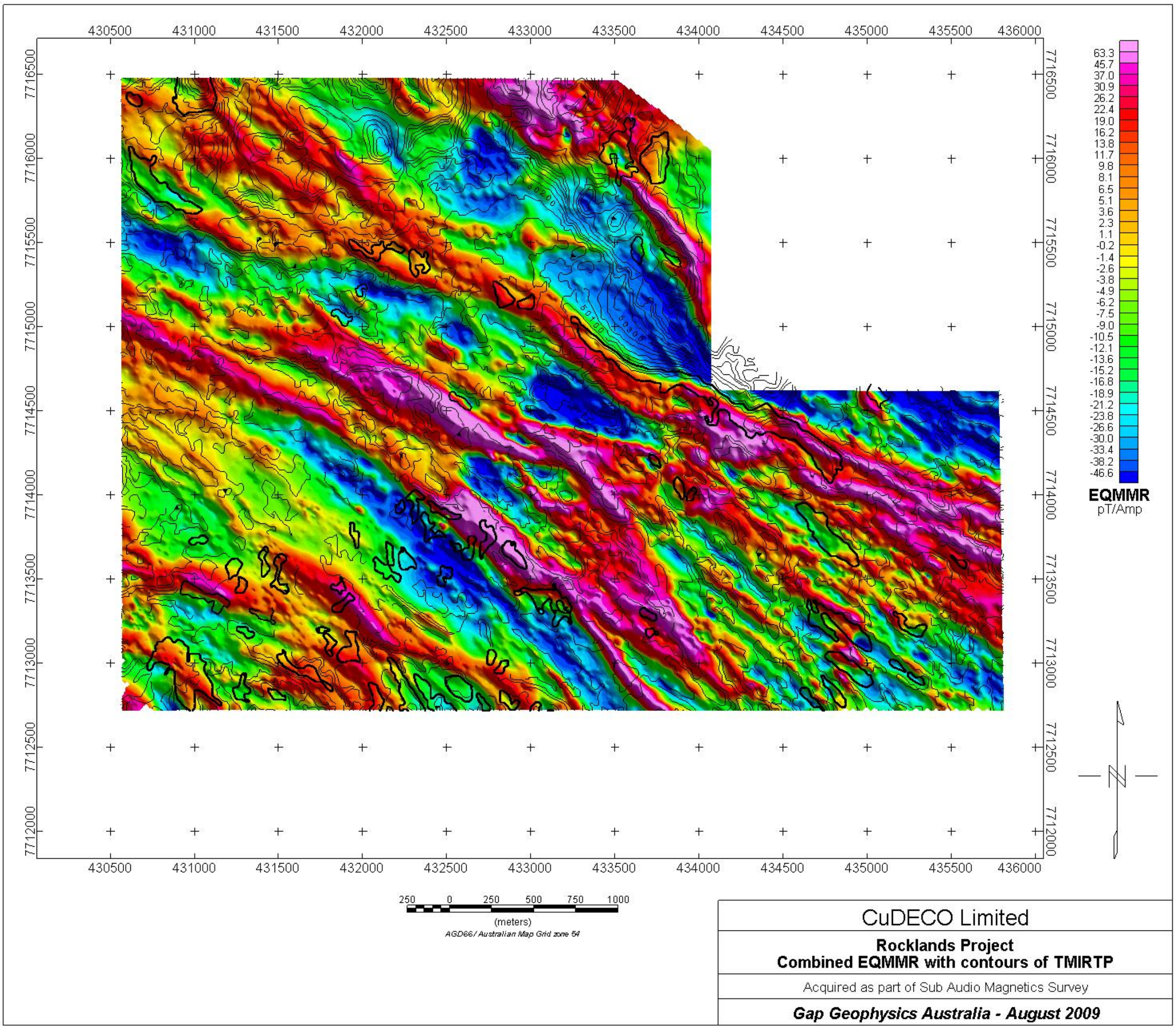

Figure 7 Rocklands Combined Grids - colour image of EQMMR with contours of TMI_RTP.

APPENDIX B – SAM SURVEY PROCEDURE AND INSTRUMENTATION

Survey Procedure

Sub-Audio Magnetics is described in an International Patent by Cattach *et al*. (1991) and in a subsequent concept paper and PhD Thesis by Cattach *et al*. (1993) and Cattach (1996) respectively. The SAM method requires a time-varying electric current to be artificially applied to the ground. This is achieved with a high power transmitter producing a broadband (low frequency square wave) signal that is introduced into the ground either through distant electrodes as for conventional gradient array ER or MMR surveys, or induced into the ground through a loop as for conventional electromagnetic surveys. In either case, the electromagnetic signal from the time-varying current induced in the ground is then measured simultaneously with the Earth's spatially varying magnetic field using a rapid sampling, total field magnetometer.

The combined signals are sampled at a fast enough rate to adequately measure the full spectrum of the artificial waveform. The signals from the two magnetic sources are spectrally distinct and with the aid of digital signal processing techniques, they may be separated and processed in real-time. The benefit of having this ability is the efficient, concurrent, high definition mapping of parameters related to the electrical characteristics of the ground as well as the spatially varying magnetic field.

For Total Field Magnetometric Resistivity (TFMMR) surveys, electrical current flow is induced galvanically through grounded electrodes. Wire connecting the electrodes is laid out in a "horseshoe" type array, similar to that shown in Figure 8. The electrodes consist of buried sheets of aluminium to which the current carrying wire is firmly attached. For safety reasons, the electrodes are at all times clearly marked with barrier mesh and warning signs as shown in Figure 9.

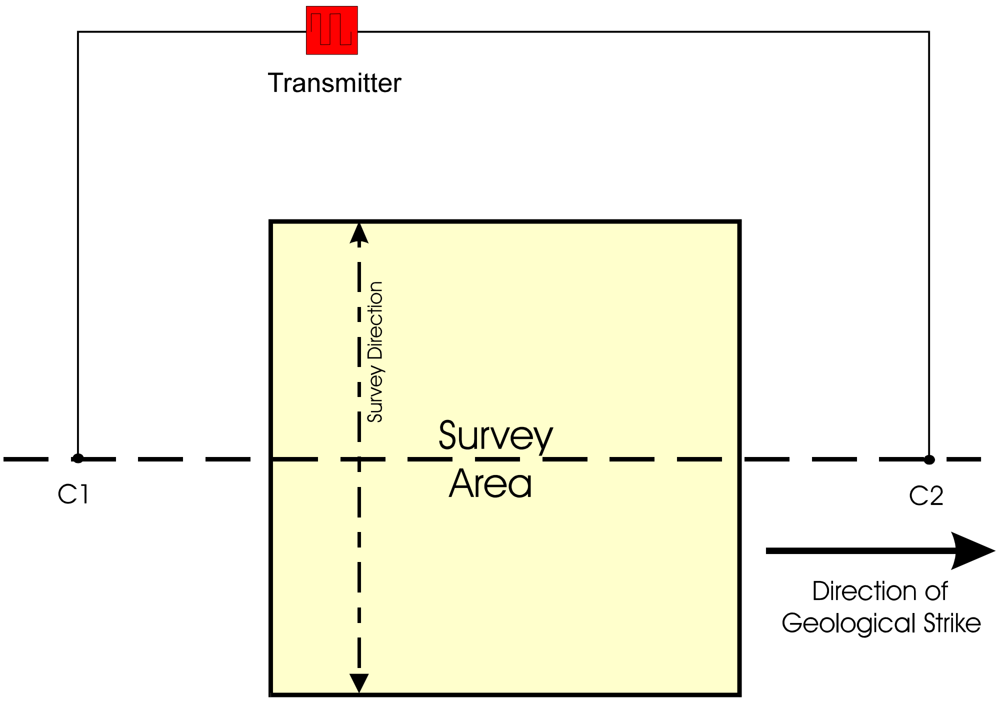

Figure 8 Typical SAM survey setup. The electrodes are placed along strike from the survey area.

Figure 9 Typical electrode setup.

The Electrodes consist of buried sheets of aluminium foil to which the current wire is firmly attached. For safety reasons, the electrodes are at all times clearly marked with barrier mesh and warning signs.

Instrumentation

The TM-6 Magnetometer

A GAP Model TM-6 magnetometer controller was used in conjunction with a caesium-vapour magnetometer sensor for this survey. The TM-6 was programmed to record Total Magnetic Intensity (TMI) readings to a resolution of 0.01nT. Measurements were logged to the TM-6 flash memory at a rate of 1200 per second.

In hand-held magnetic survey mode, the TM-6 normally requires two operators, one of whom holds the sensor (see Figure 10). The sensor is connected to the controller by a 5m coaxial cable, which enables the sensor to be separated from the controller by sufficient distance to ensure that the sensor is free from any magnetic interference produced by the control electronics.

GAP utilises differential GPS with the SAM acquisition system to assist survey navigation and positioning. This obviates the costly requirement for the client to establish control grids in the survey areas.

The SAM system employs GAP's proprietary "SurvNav" navigation software running on a hand-held computer and coupled with a Trimble AgGPS-132 differential GPS, using Fugro OmniStar real-time differential corrections. The accuracy of the DGPS is described as less than 1m.

The TM-6 and GPS units are mounted in a backpack as shown in Figure 11. Also included in the backpack are batteries to power the units and a warning system should any of the instruments malfunction.

Figure 10 The TM-6 magnetometer system in hand-held configuration.

The operators are separated by a distance of up to 5m to minimise magnetic interference from the controller.

The Cs vapour magnetometer sensor and GPS antenna are mounted on a second backpack, which enables variable sensor height. A typical sensor configuration is shown in Figure 12.

Accurate timing information necessary for the Sub-Audio Magnetics technique is provided via the AgGPS-132 receiver which outputs a 1μs "strobe" pulse every second. The strobe pulses are logged by the TM-6 in between Total Magnetic Intensity readings, thus providing the GPS time-reference for magnetic field measurements.

Base-Station

A Geometrics G856 proton precession magnetometer is used to record temporal changes in the Earth's magnetic field. The magnetometer is generally set to record Total Magnetic Intensity readings to a precision of 0.1nT once every 10 seconds.

The base-station magnetometer is located at safe distances from the transmitter arrays and other likely sources of cultural magnetic noise during the surveys. Diurnal variation data is calculated as the base-station reading minus the approximate average value at the base-station site(s) used for these surveys.

Figure 11 Backpack showing the TM-6 magnetometer controller, Trimble Ag-132 differential GPS unit and hand held PC's, for navigation and survey controls.

Figure 12 Typical sensor configuration showing the Cs vapour sensor on the left at a survey height of 2.5m. The GPS antenna is mounted on the right side of the backpack.

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Transmitter and Controller

A Zonge GGT-30 transmitter (see Figure 13) and GAP SAM-2 transmitter controller (shown in Figure 14) are used to provide the excitation source for the SAM surveys.

The SAM-2 transmitter controller is used to provide logic signals to the transmitter consistent with production of a square, bipolar waveform. The controller allows waveforms to be varied from 12.5% to 100% duty cycle with frequencies of 1Hz to 128Hz available. Waveform edges are also synchronized precisely to GPS time via timing signals received from a Trimble SV6 GPS receiver. Consequently, the transmitter controller and TM-6 magnetometer are precisely synchronised to each other. The surveys typically use a transmitter frequency of 4Hz with a 50% duty cycle.

Figure 13 The Zonge GGT-30 Geophysical transmitter.

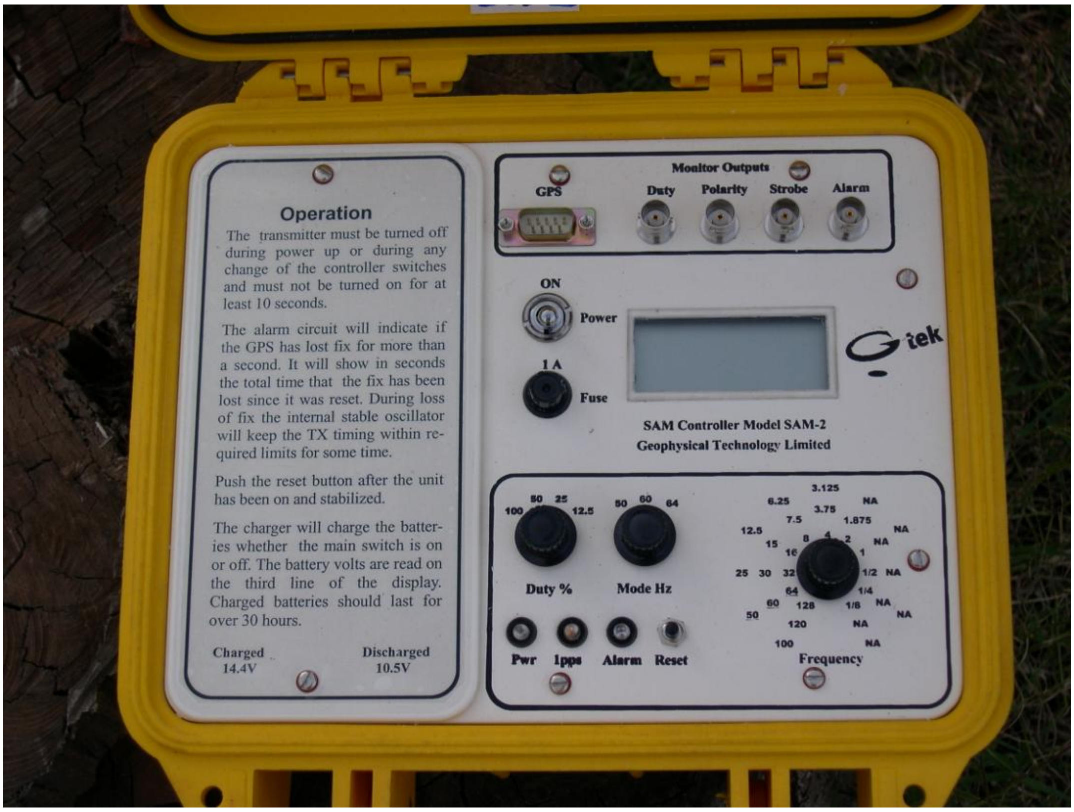

Figure 14 The GAP SAM-2 controller used to provide synchronisation and logic signals to the GGT-30 transmitter.

Data Processing

The Sub-Audio Magnetic technique measures electrical and magnetic parameters simultaneously. That is, the survey technique produces raw measurements that combine the spatial magnetic field and the temporal electromagnetic variations resulting from sub-surface current flow.

Raw magnetic field measurements taken with the SAM receiver are first digitally filtered to separate the spatial magnetic field from the temporal electromagnetic field, as illustrated in Figure 15.

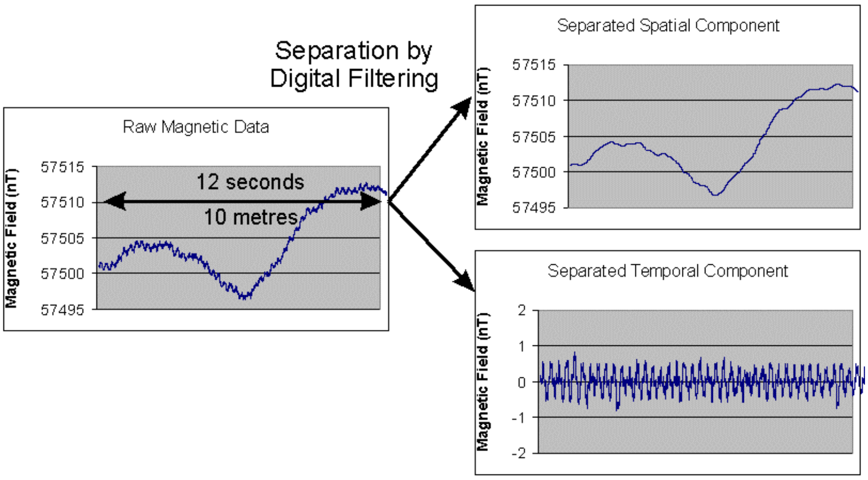

Figure 15 Separation of the Magnetic and Electrical Parameter information.

The cut-off frequency used depends on the transmitted frequency and is usually about 1.0 Hz for a 2 Hz signal or 3.0 Hz for a 4 Hz signal i.e. just below the transmitter fundamental frequency used. Signal contained in frequencies below this mark is almost purely produced by traversal through the spatially varying magnetic field. Signal above this frequency is almost purely the time-varying magnetic signal produced by current flow through the ground, induced by the transmitter.

Significant interference can be produced by mains power when in close proximity to power lines. A 50-60 Hz digital notch filter can be employed either in real-time or in post-processing if required for these situations in order to minimise the effect on the data.

Total Magnetic Intensity Data Recovery

The spatial magnetic field profile extracted from the raw SAM data is initially over-sampled, being acquired at a rate of 1200Hz for a platform moving at typically 1.5m per second. After Low-pass filtering, the magnetic profile is therefore decimated to typically 0.5m sample intervals using the position information provided by the inbuilt odometer or GPS.

Total Field Magnetometric Resistivity Data Recovery

Total Field Magnetometric Resistivity (TFMMR) data are directly indicative of galvanically induced quasi-static current flow within the sub-surface. Under controlled conditions, the Sub-Audio Magnetic technique is also sensitive to electromagnetically-excited and IP current flow, which may be measured with the Total Field Electromagnetic (TFEM) and Total Field Magnetometric Induced Polarisation (TFMMIP) parameters. Sections of the signal, which may be analysed for each of the parameters, are shown in Figure 16.

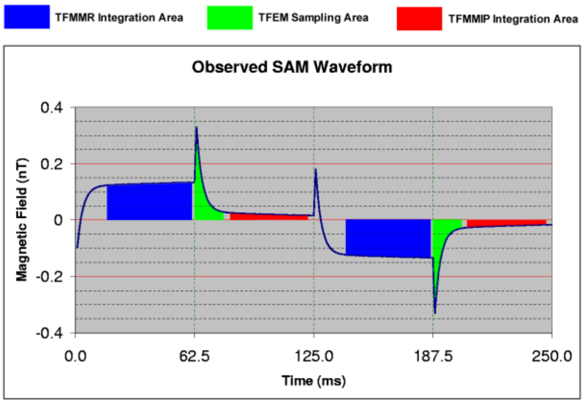

Figure 16 Example of the various sections of received waveform used to recover the various electrical parameters. This example is for the case where a 4Hz, 50% duty cycle wave has been used.

Consecutive waveforms separated from the spatial magnetic field are stacked (typically 4-fold) to enhance the signal-to-noise ratio of the waveform. TFMMR values are then computed by integrating beneath the waveform during the transmitter on-time (typically from 35.0ms to 55.0ms after current switch-on for a 4Hz signal). Normalization of TFMMR values is performed by dividing the integration time by the transmitter current used. The uncorrected TFMMR values thus determined have units of picoTeslas / Amp.

As TFMMR data represents response to current flow in a particular direction, but is rectified from an alternating (bipolar) signal, two polarities for the data are possible depending on how waveforms are "rectified". In recognition of this fact, a convention is adopted whereby for a north-south oriented survey grid, the sign of the TFMMR data assumes the Southern electrode was a current source and the Northern electrode a current sink (i.e. Current flow through the ground from South towards the North). Similarly, for an east-west oriented grid, the convention is adopted whereby the sign of the TFMMR data assumes the Eastern electrode was a current source and the Western electrode a current sink (i.e. current flow through the ground from East towards the West).

Primary and Normal Corrections

The theoretical fields produced by the wire feeding the electrodes (Primary field) and current flowing through a homogenous half-space (Normal field) are computed and subtracted from the TFMMR data. The resulting corrected TFMMR data is therefore purely anomalous and the consequence of perturbations in current flow caused by lateral conductivity variations.

Equivalent MMR Transformation

The TFMMR parameter is a total-field measurement that is made in the presence of the large background magnetic field of the Earth. This results in the TFMMR field being a pseudo-component measurement made in the direction of the Earth's magnetic field. As this component direction is variable from site to site and grid to grid, TFMMR data is generally non-standard and not intuitively interpreted.

The equivalent MMR transform was developed by Boggs (1999) to provide a standard, intuitive presentation format for TFMMR data. The transform converts data to a horizontal component perpendicular to the axis of the electrode spread used in the survey. More accurately, the Equivalent MMR data standard is defined by the following:

> *Assume a right-handed coordinate system with "up" corresponding to the +Z spatial direction. Now, if the TFMMR data are recovered to produce a response that assumes current flow in (say) the +Y spatial direction between electrodes, then the "Equivalent MMR" data is the calculated component data in the +X spatial direction (perpendicular to the electrode spread).*

In equivalent MMR format, data is more readily related to underlying resistivity structure. In general terms, MMR highs may be associated with underlying features that are relatively conductive and lows with resistive features.

Interpretation of Equivalent MMR

Because of a simple relationship between the horizontal component magnetic field generated by two-dimensional current flow and the gravity field of two-dimensional structures (eg. Szarka, 1987), a common, simple method of interpretation of two-dimensional MMR anomalies is to use gravity modelling software. In this case, density becomes analogous to current density within the modelled structures. MMR highs equate to areas of higher current concentration and therefore the sub-surface carrying this increased current is likely to have higher conductivity.

References

Boggs, D.B., 1999. The Theory and Application of Sub-Audio Magnetic Data Acquisition and Numerical Modelling. PhD Thesis – University of New England.

Cattach, M.K., Stanley, J.M. and Lee, S.J., 1991. Sub-Audio Magnetics Instrument. International Patent No: PCT/AU91/00238.

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